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(71) Applicant *(for all designated States except US)*: SOUTHERN RESEARCH INSTITUTE [US/US]; 2000 Ninth Avenue South, Birmingham, AL 35205 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: JACKSON, Thomas, E. [US/US]; 3420 Sagewood Trail, Birmingham, AL 35243 (US). HUSMAN, George, E. [US/US]; 320 Bradberry Lane, Birmingham, AL 35242 (US).

(74) Agents: PETTIT, George, R. et al.; Pollock, Vande Sande & Amernick, 1990 M Street, N.W., #800, Washington, DC 20036 (US).

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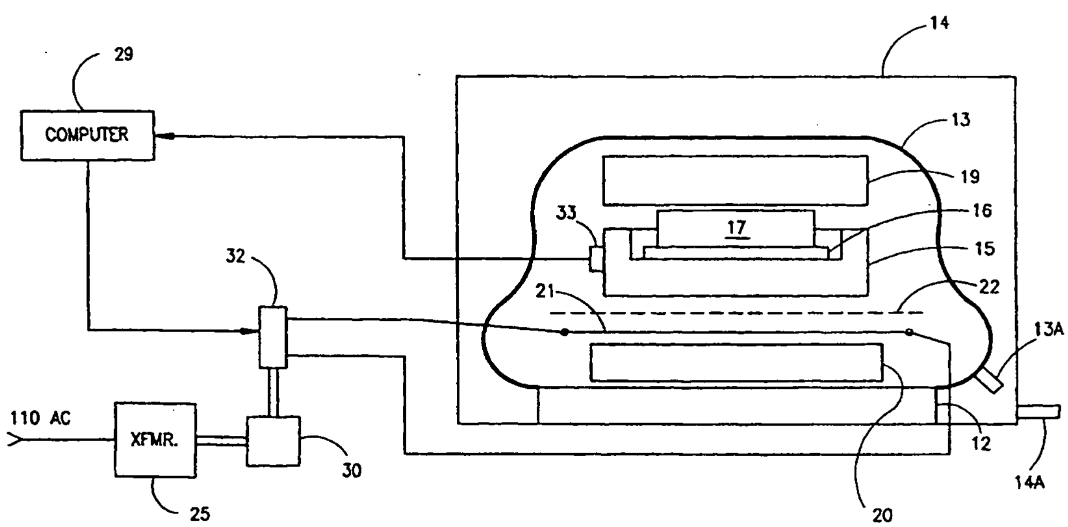

(57) Abstract

A method and apparatus for heating composite or plastic materials which are formed into a final product. Heat is generated from a carbon fabric which may be embedded in a ceramic tool base using conventional ceramic molding techniques. The generated heat is uniformly distributed over the surface area of the carbon fabric, and the heat transfer from the ceramic tool base to the composite or plastic material may be controlled to maximize heat flow into the composite or plastic material. The heat source and material being formed may be placed in a vacuum environment to aid in the formation of the material about a mold surface. The temperature of the material being formed may be maintained at a constant temperature by controlling the current supplied to the carbon fabric in proportion to a measured temperature. The heat source may include cooling channels which permit the ceramic tool to be cooled to expedite processing following forming of the composite or plastic material.

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HEATED TOOLING APPARATUS AND METHOD FOR PROCESSING COMPOSITE AND PLASTIC MATERIAL

Thomas E. Jackson

FIELD OF THE INVENTION

The present invention relates to methods and apparatus used for heating and forming used in the fabrication of composite and plastic materials. Specifically, heated tooling and processes are provided which may be implemented in vacuum bag molding, resin transfer molding, and other molding processes.

BACKGROUND OF THE INVENTION

Composite and plastic materials are used to fabricate products using various molding techniques and devices. The process of fabricating composite materials usually requires that heat be supplied to the product material which results in that material assuming the form of a mold surface. In some cases, the heating also provides activation for chemical curing or some other desired chemical or morphological change in the material during the processing. The management of heat flow into the composite material during processing is critical to the forming and/or chemical change of the part and is usually critical to the part quality and application performance.

Often in the thermal processing of composite and plastic materials, the thermal mass of the tooling combined with the inefficiencies of the heating equipment used (e.g., autoclaves and platen presses) results in prolonged cycle times to achieve the required temperature profile to the part being fabricated. As a result, the thermal processing cycles are usually defined by these tooling and equipment limitations rather than the optimum cycle for the material being processed. Further, this prolonged cycle time results in

lower productivity, often requires multiple tool sets, and always results in increased costs.

By controlling the heat so that it predominantly flows into and out of the part being processed, the problems described above can be eliminated, and much more efficient and cost effective processing can be achieved. Further, for processing materials that require temperatures greater than 500°F, such as thermoplastics, glass, or ceramic matrix composites, vacuum bag processing is often difficult or impossible because high temperature bagging materials and sealants are required. Thermal management into and out of the part can keep all of the heat focused in the part allowing low temperature vacuum bags and sealants to be used for very high temperature (> 2000°F) processes.

These processing improvements are achieved through well controlled, uniform heating and cooling localized at the part being processed along with good thermal management of the tool and the surrounding environment.

SUMMARY OF THE INVENTION

The invention provides for a method and apparatus which is capable of heating composite and plastic materials which are formed into parts. The heat is generated from a carbon fabric which is either embedded near the surface of a cast tool base, or supported above a tool base in proximity to the composite material being formed. The tooling using this heating technique can be a closed cavity mold, as is used in resin transfer molding or compression molding, or one-sided tooling, as is used in vacuum bag molding.

In order to focus the thermal energy into the part being processed, the base tooling material is preferably a thermal insulator, causing heat flow into the part rather than into the tool. Similarly, in the one-sided tool approach,

insulation materials are preferably placed on top of the part being processed, causing heat flow into the part rather than the surrounding environment, vacuum bag, or sealant materials.

DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates one embodiment of the invention for forming a laminate of ceramic matrix/carbon fiber composite material;

Figure 2 is a photomicrograph of the laminate produced by the embodiment of Figure 1;

Figure 3 is a photomicrograph of the laminate produced by the embodiment of Figure 1 at an increased magnification;

Figure 4 illustrates an embodiment of the invention having a self heated tool comprising a carbon fabric embedded in a castable ceramic;

Figure 5 illustrates an embodiment of the invention using multiple heat zones in a vacuum forming operation;

Figure 6 illustrates a tooling master for forming a heating tool having a complex heating surface;

Figure 7 illustrates the step of applying a release layer to a tooling master of Figure 6;

Figure 8 illustrates the step of building a perimeter about the tooling master;

Figure 9 illustrates the step of inserting a carbon fabric in the castable ceramic;

Figure 10 illustrates adding a layer of cast ceramic on back of carbon fabric;

Figure 11 illustrates the step of adding a wax cooling channel which has been preformed in the casting material;

Figure 12 illustrates the step of adding a quantity of castable ceramic material to the back surface of the mold;

Figure 13 illustrates the heating tool which has been separated from the tooling master; and

Figure 14 illustrates a heating tool in accordance with another embodiment of the invention implemented in a resin transfer mold.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 illustrates one embodiment of the invention for curing high temperature composite materials. The method carried out in accordance with Figure 1 provides a low temperature cure operation using a vacuum bag 13, followed by a high temperature post cure in an inert atmosphere using pressure vessel 14. The initial curing operation and high temperature post cure operation are combined into a single operation using a silicone rubber vacuum bag 13 and a pressure chamber 14.

As a starting material, a preceramic-alumina matrix, available from Applied Polaramic, Inc., is applied to a T-300 carbon fiber tow on a filament winding mandrel, as is known. The resulting material 16 is placed in a steel pocket die 15, and a steel caul plate 17 is placed over the material 16. A temperature sensor 33 is adhered to the wall of the pocket die 15 to monitor the temperature of the material 16 as it cures. A plain weave carbon fabric 21 is utilized as the source of heat for curing the material 16. The carbon fabric 21 is located between first and second insulation layers 20 and 22, electrically isolating the carbon fabric from the pocket die 15, while maintaining the pocket die 15 in close heat transfer relationship with the carbon fabric 21. A further thermal insulation layer 19 is applied above the pocket die 15 to keep the silicone rubber vacuum bag 13 at a safe operating

temperature. Layer 20 also serves as a thermal barrier directing the heat toward the composite material 16.

The entire vacuum bag 13 assembly is enclosed in a pressure vessel 14, so that an inert gas overpressure can be applied during the processing operation to the vacuum bag 13, and hence to the ceramic matrix composite material 16 being formed by the pocket die 15.

The thermocouple 33 provides a temperature measurement to a computer 29. Computer 29, in turn, is connected through an interface and enables the controller 32 to apply a heating current to the carbon fabric 21. The computer 29 and thermocouple operate as a thermostat to maintain the temperature of the pocket die 15 at a desired temperature. Variable transformer 25, and step down transformer 30 provide the operating current for the carbon fabric 21 under control of controller 32. Using the foregoing apparatus, a low temperature cure of the preform step of a curing process may be performed. Current is supplied by controller 32 to the carbon fabric 21, and the temperature of the tool is increased to 300°F in a linearly increasing temperature for a two hour period. A compressed air overpressure of 50 psi is applied through inlet 14a of pressure vessel 14, and the vacuum bag internal pressure is set to be approximately 25 inHg (substantially 12 psi subatmospheric pressure). Following the low temperature cure of the preform, the heated ceramic matrix composite 16 conforms under pressure to the surface of the pocket die 15.

A high temperature post-cure step is performed by applying a vacuum through inlet 13a within vacuum bag 13, and the pressure vessel 14 was supplied with argon gas to a pressure of 45 psi. Under the established pressure conditions, the temperature was increased from room temperature to 500°F over a two hour period, and maintained for approximately two hours, and then increased from 500 F to 1400°F over three hours and held

there for two hours. A cooling interval followed, while maintaining a vacuum at 25 inHg during a cool down and simultaneously bleeding off the argon gas pressure from the pressure vessel 14.

The foregoing apparatus and method produces a laminated panel of ceramic matrix carbon fiber reinforced composite having a density, flexural strength and modulus equal to or superior to manufactured laminate using the same matrix material. Table 1 indicates for various temperatures, a comparison between manufactured Alumina-alumina laminates, and a carbon alumina laminate manufactured in accordance with the method and apparatus of Figure 1. The most notable difference is seen in the density and flexural strength of the different materials. The carbon fiber laminate made in accordance with the method and apparatus of Figure 1 is stronger. The carbon/alumina system using the post-cure process in accordance with Figure 1 had higher strength and modulus at room temperature over the manufactured ceramic matrix precursor.

Table 1. Comparison of properties of two materials and several processes

Material/Process	Temperature (deg F)	Density (g/cc)	Flexural Strength (Ksi)	Modulus (Msi)
Alumina-alumina/mfgr	Room	2.6	26	8
Alumina-alumina/mfgr	1400	2.6	38	7.6
Carbon-alumina/free stand post-cure	Room	1.97	59 75	11 15
carbon-alumina/ overpressure post-cure	Room	1.99	>32 (failure in shear)	10.09
carbon-alumina/ overpressure post-cure	1400	1.99	>32.8 >37.8 (failure in shear)	9.79 8.74

Figures 2 and 3 are photomicrographs taken at a magnification of 25X and 100X, respectively, of a section of carbon fiber/alumina matrix laminate processed in accordance with the technique of Figure 1. The carbon fibers, represented by white dots in the photomicrograph, are not uniformly distributed in the matrix material which is due primarily to the characteristics of the prepreg not to the application of the technique. Therefore the variation in the flexural strength limits due to shear mode failure and lower modulus values in comparison to free-standing post-cures result from variation in prepreg materials. The Figure 2 illustrates cracking, which was the result of a unidirectional layout of the materials in the pocket die. Figure 3 further illustrates a material heterogeneity that contributed to the mechanical performance variations.

This embodiment of the described tooling method demonstrates that conventional vacuum bag technology can be used to process ceramic matrix composites at temperatures of 1400°F, and higher, as a final post cure temperature for these materials.

Figure 4 illustrates another embodiment of the foregoing process and apparatus, utilizing a self-heated tool. The self-heated tool of Figure 4, which may be used in place of the separate carbon fabric of Figure 1, provides for greater management of the heat transfer from a heated fabric layer to a thermally processed material used in a molding operation. The self-heated tool shown in Figure 4 comprises a ceramic matrix forming an insulating substrate 34 having a carbon fabric 36 embedded therein. The body of the tool may also be cast from polymer materials such as epoxy, polyester, or polyurethane depending upon the temperature requirements of the process. Additionally, cooling channels 35 may be embedded within the ceramic matrix substrate 34 to provide additional control over the temperature of a heated surface 40. Electrodes 38 and 39 are shown

connected to the ends of the carbon fabric 36. Electrodes 38 and 39 may simply be a continuation of the carbon fabric layer 36, or may include metal electrodes formed in the ceramic matrix substrate 34 which are connected to the ends of the carbon fabric 36. Hollow glass or phenolic microspheres may also be embedded in the ceramic matrix substrate 34 to minimize heat transfer to surface 41. The insulating substrate 34 may also be formed using castable polymers with insulating fillers depending upon the temperature requirements of the process.

Use of the broad layer of woven carbon cloth 36 and the insulating substrate 34 provides for a large uniform heating element which may be used for thermoprocessing of thermoplastic, thermoset, or pre-ceramic materials. The insulating substrate, which may be a ceramic matrix, permits high temperatures to be realized on the surface 40, may also in low temperature applications be made of other materials, including a polyurethane foam. In this case as well, the heat will be transferred preferentially to the surface 40, while maintaining a high measure of temperature insulation with the opposite surface 41 of the self-heated tool.

Figure 5 is an embodiment of the invention having multiple heat zone configurations in a vacuum forming operation. A self-heated tool 42, in accordance with that of Figure 4 (without cooling channels) heats the base of a thermoplastic material 45. A release layer 46 is shown over which the prepreg composite material 45 may be disposed. The material 45 has an irregular shape supplied by a pair of heated mandrels 47, 48. The mandrels 47, 48 are used to form reinforcing ribs in the panel 45 having a rectangular cross section. Heated mandrels 47, 48 may also be a self heated ceramic tool of the type shown in Figure 4, comprising an insulating substructure 34 containing an embedded carbon fabric 36. In this way, multiple heat sources may be used to form an irregularly shaped composite

material 45. Once the composite material 45 has been processed, the mandrels 47 and 48 may be removed from an enclosure of composite material 45.

A release layer 49 is shown, conformally coating the thermoplastic material. A breather layer 50 is also shown which will let gases escape during processing, which are in turn drawn from the vacuum bag 52.

The use of the foregoing heated tool permits application of the heat in the process material with a minimum amount of loss to the surroundings or other parts of the tooling which need not be heated.

The carbon fabric includes distinct advantages as a source of heat for thermoprocessing composite materials. The carbon fabric tends to produce a uniform temperature distribution, and the coefficient of thermal expansion is very low. The thermal conductivity of the fabric tends to diffuse the generated heat minimizing the localized hot spots. The width of commercially available carbon fabric may be as much as 60 inches and has a long life. The fabric is low cost, and is capable of a very high temperature operation when it is protected from oxidation.

The ceramic tooling material compliments the carbon fiber in that it also has a high temperature capability and low coefficient of thermal expansion. A silica-based castable ceramic has thermal expansion properties that match the carbon fabric, as well as the thermal expansion properties of the carbon fiber composites which may be processed thereby reducing the internal stresses generated in the part when it is processed in intimate contact with the heated tooling surface.

The combination of a cast ceramic and carbon fiber fabric provides a wide range of temperature operation and excellent thermal shock capability useful for processing thermoset composites, thermoplastic composites,

glass matrix and ceramic matrix composites, alumina matrix composites and even carbon/carbon composites.

The heated tool may also be fabricated with a heating surface having a complex shape. While the example of Figure 5 provides a technique for manufacturing laminated sheets having a reinforcing rib formed by the mandrels, the entire heating surface of the heating tool may be cast in a form for applying heat to a complementary complex shape.

Figures 6-12 illustrate the process steps for forming the heated tool having a heating surface with a complex shape. Figure 6 illustrates a tooling master 60, having a surface 61 representing the desired shape of a heated tool surface. In Figure 7, a release film is applied to the complex surface 61 which inhibits a subsequently formed layer from sticking to the master 60.

A container 62 is formed in Figure 8 about the perimeter of the tooling master 60 representing the size of the tool to be cast on the complex tooling master 60.

A sufficient quantity of castable tooling material is created. The castable tooling material can be, for instance, castable silica based on a ceramic activator known as RESCOR 750. The casting material is vibrated to remove air bubbles and a thin layer of the castable material 63 is placed over the surface 61 in Figure 9. A precut carbon fabric 64 is layed over the thin casting material 63 and the ends extend to the container 62, where it extends vertically along the container 62 surface. The ends of the carbon fabric 64a and 64b are available to provide electrical connections to the carbon fabric 64. A layer of ceramic 65 is added over the carbon fabric in Figure 10.

Figure 11 illustrates the step of adding a wax cooling channel 66 which has been preformed in the casting material on the back side of the

carbon fabric 64. Carbon fabric 64 is coated with a thin coat of casting material 63 and 65, and the casting material is allowed to set to avoid disturbing the position of the wax cooling channel 66. A quantity of castable tooling material is poured onto the back surface of the mold in Figure 11, covering the wax channel. A layer of fiberglass cloth or carbon cloth, as mechanical reinforcement, has been placed on top of the castable tooling material 68 in Figure 12. The remaining castable insulation is poured over any reinforcement material to a level determined by a designer to strengthen the tool. The back surface is finished with a trowel to form a smooth contour. Once the cast material has cured, the cast mold is removed as shown in Figure 13 from the master tool. Post cure heating of the mold may be useful as is known to those skilled in the mold making art, to fully remove the residual moisture from the mold.

The finished mold, therefore, contains a surface 69 which is heated from electrical current applied to ends 64a and 64b of the carbon fabric. Heat from the carbon fabric is transferred to surface 69 where it may be used to heat a complex shape of a thermoplastic material, or a die of a mold supporting the thermoplastic material.

Creating a tool in accordance with the foregoing produces a uniformly heated surface of castable material adjacent to the carbon fabric. In one prototype tool in accordance with the foregoing, having a surface area of approximately 14" x 14", the average temperature measured was 590.9°F, with a coefficient of variation of 1.75% of a sampled area. The tool temperature falls off significantly towards the edge of the tool by virtue of the insulation properties of the ceramic base material. Heat flow through the tool surface facing the component being formed may be further enhanced by using materials having a high thermal conductivity adjacent the heated fabric.

The foregoing integrally heated processing tool may also be used in vacuum bag applications similar to those of Figures 1 and 5. The vacuum bag membrane is insulated from the heated assembly with a flexible insulation layer.

The heated surface generates sufficient heat to form a thermoplastic composite along the molded surface of the tool. The low temperature vacuum bag membrane remains unaffected due to the insulation layer. Further, the tooling substructure has a ceramic base which insulates the vacuum table supporting the tooling from high temperatures.

Thus, it can be seen that the foregoing tool by controlling the heat flow such that a majority of the heat flow is incident to the component being formed, permits lower temperature environments to be used in the vacuum bag forming process.

The present invention can also be implemented in a resin transfer mold (RTM) to produce composite components which are formed on a heated surface. Referring now to Figure 14, there is shown a separated two-part RTM mold in accordance with another embodiment of the invention. The two-part RTM mold applies heat from two directions against a castable material which is injected through an opening in the top half of the mold.

The bottom half of the two-part RTM mold 90 includes a ceramic base 91 material formed by conventional molding techniques, having embedded near a top surface heating fabric 93 for shaping a castable material such as a thermoplastic material. The heating fabric faces 93 on a lower side thereof a cooling channel 94, similar to the ones formed in the embodiment of Figure 4. The ends of the heating fabric are connected to terminals 96, 97 on the exterior of the lower mold half and a thermocouple sensor 98 is provided which may be used to control the temperature of the heating fabric 93.

An upper mold half 100 is also provided having an embedded heating fabric 103 adjacent a lower surface thereof. A thermocouple sensor provides an accurate monitoring and control of the temperature. The upper mold half also includes a ceramic base material 99 which reduces the heat flow through the top of the upper mold half, directing the heat flow towards the lower mold half. A cooling channel 104 may also be provided in the upper mold half ceramic base which is opposite the upper side of the heating fabric 103. A pair of terminals 108, 109 are provided to supply current to the heating fabric 103.

The two-part resin transfer mold directs heat from two directions against a castable material which has been injected through an opening 106 in the mold, and which extends into the space 101 formed in the lower surface of the upper mold, and upper surface area of the lower mold 92 which are shaped to form the component surface. Thus heat is directed to the material being molded, increasing the efficiency of heat transfer to the component being formed between mold halves.

The foregoing description of the invention illustrates and describes the present invention. Additionally, the disclosure shows and describes only the preferred embodiments of the invention, but as aforementioned, it is to be understood that the invention is capable of use in various other combinations, modifications, and environments and is capable of changes or modifications within the scope of the inventive concept as expressed herein, commensurate with the above teachings, and/or the skill or knowledge of the relevant art. The embodiments described herein above are further intended to explain best modes known of practicing the invention and to enable others skilled in the art to utilize the invention in such, or other, embodiments and with the various modifications required by the particular applications or uses of the invention. Accordingly, the description

is not intended to limit the invention to the form disclosed herein. Also, it is intended that the appended claims be construed to include alternative embodiments.

CLAIMS

1. A self heated molding tool comprising:

a cast ceramic tool base having embedded therein a layer of carbon fabric extending the length of said ceramic tool base and adjacent a surface thereof, said carbon fabric generating heat which is transferred to said surface when a voltage potential is applied to first and second ends of said carbon fabric;

cooling conduits embedded in said ceramic tool base between said carbon fabric and an opposite surface of said ceramic tool base; and

a die in heat transfer relationship with said surface,said die receiving a molding substance which is heated by a surface of said die.

2. The self heated molding tool according to claim 1 further comprising a vacuum enclosure surrounding said cast ceramic tool base and said die which aids said molding substance to conform to a surface of said die.

3. The self heated molding tool according to claim 1 wherein said ceramic tool base comprises a castable, silica based ceramic and activator.

4. The self heated molding tool according to claim 3 wherein said ceramic tool base includes fiber reinforcement materials for increasing the strength of said ceramic tool base.

5. The self-heated molding tool according to claim 3 further comprising hollow phenolic or glass microspheres embedded in said ceramic tool base forming an insulation layer adjacent to a surface opposite said surface in heat transfer relationship with said die.

6. A method for making a self heated molding tool comprising:

creating a tooling master which defines a shape of a tooling surface;

forming a thin layer of casting material over said tooling master;

forming a layer of precut carbon fabric over said casting material;

forming a second thin layer of casting material over said layer of carbon fabric; and

after curing, removing said layers of casting material including said carbon fabric from said tooling master.

7. The method for making a self heated molding tool according to claim 6 further comprising inserting a wax cooling channel in said casting material in contact with one side of said carbon fabric, over which said second thin layer of casting material is formed.

8. The method according to claim 7, further comprising covering said wax channel with additional casting material.

9. The method according to claim 8 wherein said additional casting material contains reinforcement material.

10. The method according to claim 6 further comprising curing said layers of casting material by heating said layers of casting material including said carbon fabric after removing said layers of casting material and carbon fabric from said tooling master.

11. The method according to claim 6 further comprising forming electrodes on first and second ends of said carbon fabric which are adapted to be connected to a source of electric potential.

12. A method for creating molded articles comprising:

creating a self heated molding tool of a ceramic casting which includes an embedded carbon fabric, said carbon fabric having first and second ends which are adapted to be connected to a source of electric potential;

positioning a die in heat transfer relationship with said self heated molding tool;

covering a surface of said die with a molding material which conforms to said die when heated; and

enclosing said die in a vacuum enclosure whereby said molding material conforms to said die surface in response to heat being supplied to said die from said self heated molding tool and a pressure resulting from said vacuum;

monitoring the temperature within said vacuum enclosure; and

controlling the current to said molding tool carbon fabric so as to maintain a constant temperature within said vacuum enclosure.

13. The method according to claim 12 further comprising:

removing said die and molding tool from said vacuum enclosure, and applying a pressure to said molding material on said die surface to consolidate said molding material.

14. A method for processing high temperature composite materials comprising:

placing high temperature composite materials in a pocket tool die and covering with a steel caul plate cover;

locating a carbon fabric in heat transfer relationship with said pocket tool and electrically insulated therefrom;

enclosing said pocket tool die and carbon fabric with a vacuum bag;

locating said vacuum bag in a pressure vessel;

pressurizing said pressure vessel while simultaneously drawing a vacuum in said vacuum bag; and

applying a voltage potential to first and second ends of said carbon fabric while establishing a vacuum in said vacuum bag whereby heat is generated and transferred to said pocket tool.

15. The method for processing high temperature composite material according to claim 14 wherein said step of pressurizing said pressure vessel occurs following a low temperature heating of said pocket tool die.

16. The method for processing high temperature composite material according to claim 15 further comprising heating said pocket tool die to a higher temperature during said step of pressurizing said pressure vessel.

17. The method for processing high temperature composite material according to claim 16 wherein said pocket tool temperature is increased in at least two steps during pressurization of said pressure vessel.

18. The method for processing high temperature composite material according to claim 17 wherein following said two steps, said pocket tool is cooled.

19. The method for processing high temperature composite material according to claim 18 wherein pressure in said pressure vessel is bled off following said two step temperature increase.

20. The method for processing high temperature composite material according to claim 17 wherein said two steps comprise:

heating said pocket tool to 500°F for over two hours, and then heating to 1400°F for two hours.

21. The method for processing high temperature composite material according to claim 14 wherein said voltage potential is regulated to establish a temperature for said pocket tool of 300°F.

22. A method for controlling heating and cooling during thermal processing of a component comprising:

locating material for forming said component on a tooling surface;

insulating said tooling surface on at least one side thereof for directing thermal energy into said component; and

heating said component material by placing a carbon fabric connected to a source of electric power in proximity to said component material whereby thermal energy is transferred from said carbon fabric to said material which is heated and assumes the shape of said tooling surface.

23. The method for controlling heating and cooling during thermal processing according to claim 22 wherein said carbon fabric is embedded in said tooling surface.

24. The method for controlling heating and cooling during thermal processing according to claim 22 wherein said carbon fabric is embedded in said tooling surface adjacent to said component material.

25. The method for controlling heating and cooling during thermal processing according to claim 22 further comprising:

enclosing said tooling surface and carbon fabric in a vacuum enclosure whereby a vacuum pressure urges said component material against said tooling surface.

26. The method for controlling heating and cooling during thermal processing according to claim 22 further comprising:

embedding insulating particles in said tooling surface for insulating said tooling surface.

27. A resin transfer mold for producing components comprising:

a first mold half comprising a heater fabric embedded in the surface of a ceramic base having a contour which defines a surface of said component; said heater fabric being connected to first and second terminals;

a second mold half disposed above said surface of said ceramic base which has a heater fabric embedded in a surface of a second ceramic base having a contour which defines a second surface of said component,

said heater fabric having third and fourth terminals, said second mold half including an opening to receive castable material which is received between said first and second ceramic base surfaces;

said first mold half and said second mold half directing heat produced by said first and second heater fabrics to said castable material between said first and second ceramic base surfaces.

28. A resin transfer mold for producing components according to claim 27 further comprising:

first and second cooling channels in said first and second ceramic bases for increasing the cooling rate of said castable material between said first and second ceramic base surfaces.

29. The resin transfer mold for producing components according to claim 28 wherein said first cooling channel is located on a side of said heating fabric which faces away from said surface of said first ceramic base having said contour surface of said castable component.

30. The resin transfer mold for producing components according to claim 29 wherein said second cooling channel is located on a side of said second heating fabric which faces away from said surface having said contour on said second ceramic base.

31. The resin transfer mold according to claim 27 further comprising:

a thermocouple device associated with at least one of said heating fabrics for monitoring the temperature of said fabric.

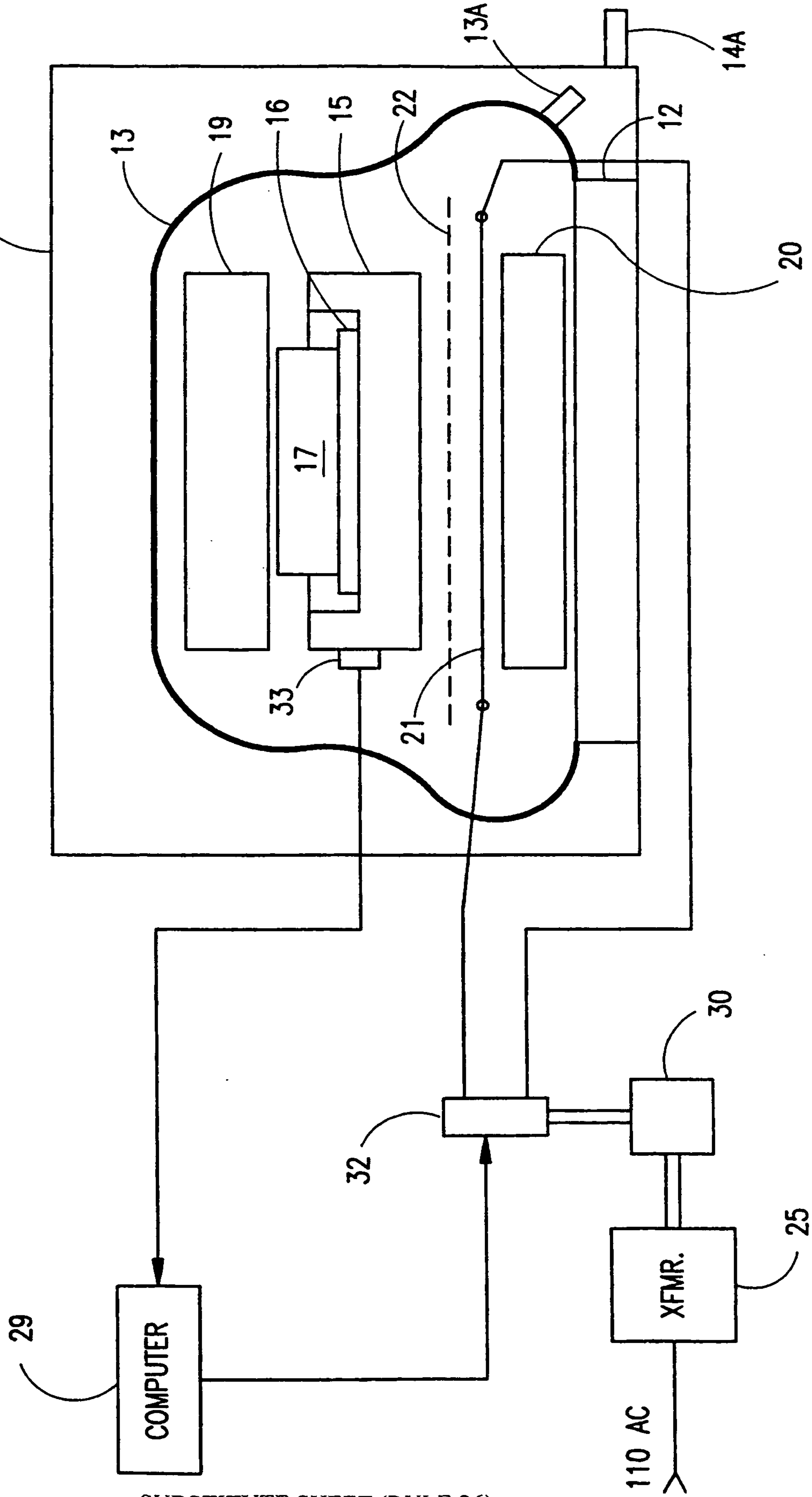
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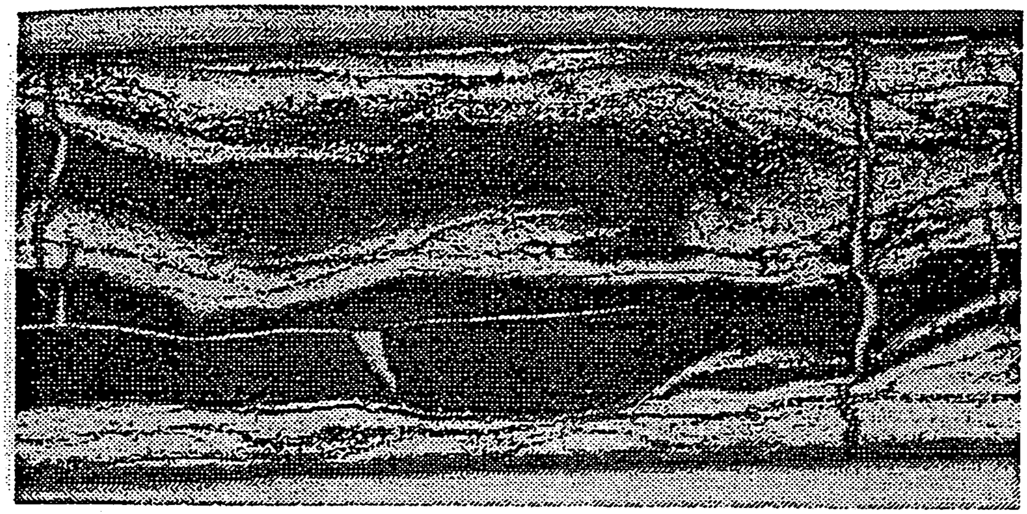
FIG. 1



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F I G. 3

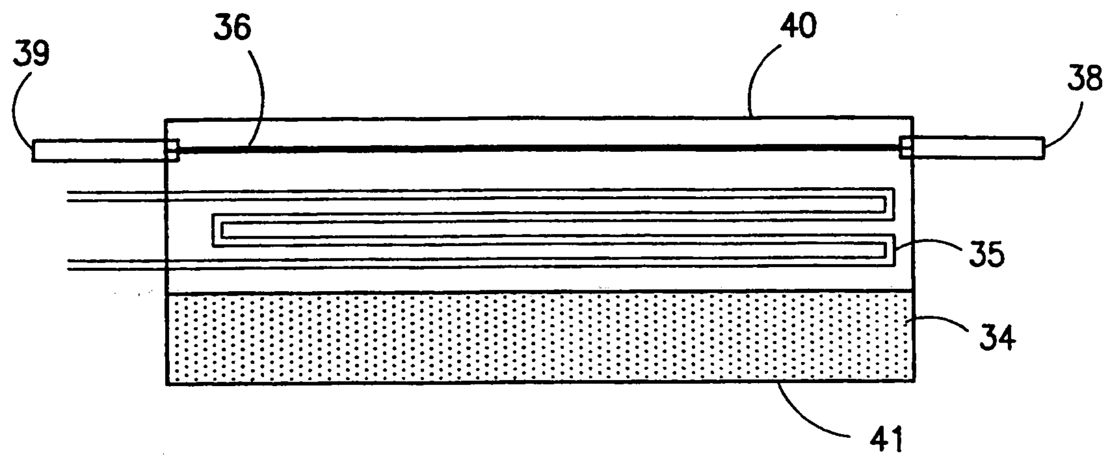

FIG. 4

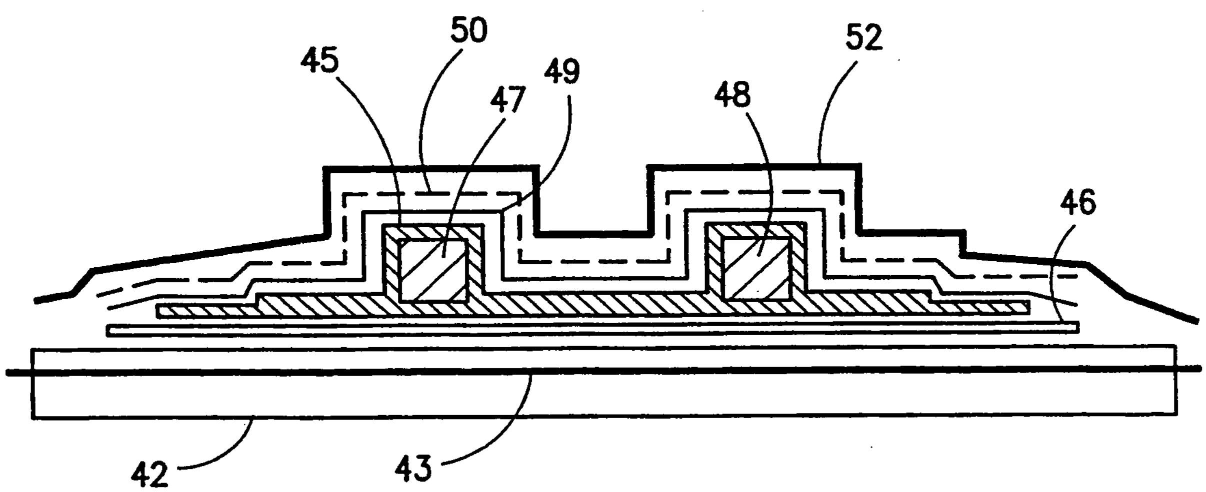

FIG. 5

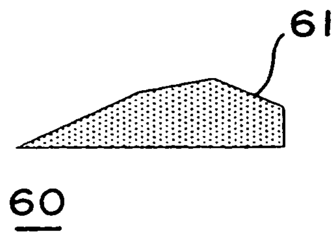

FIG. 6

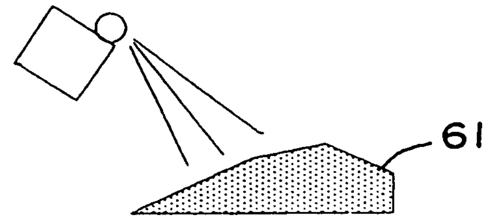

FIG. 7

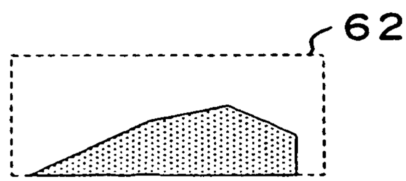

FIG. 8

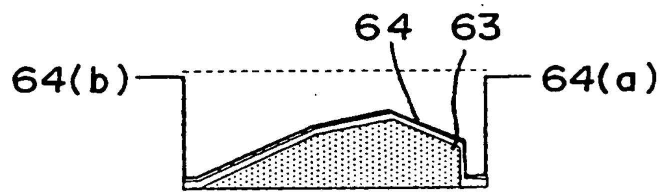

FIG. 9

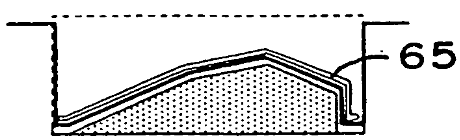

FIG. 10

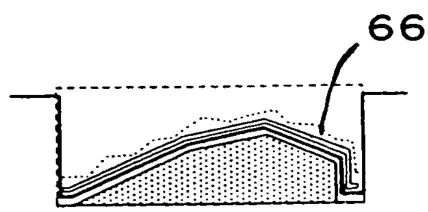

FIG. 11

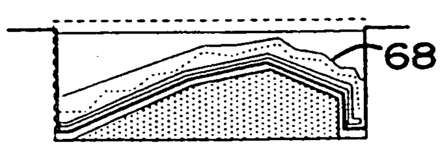

FIG. 12

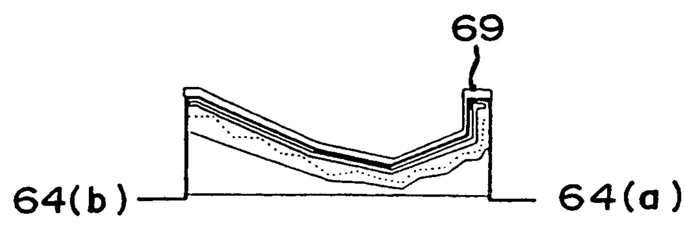

FIG. 13

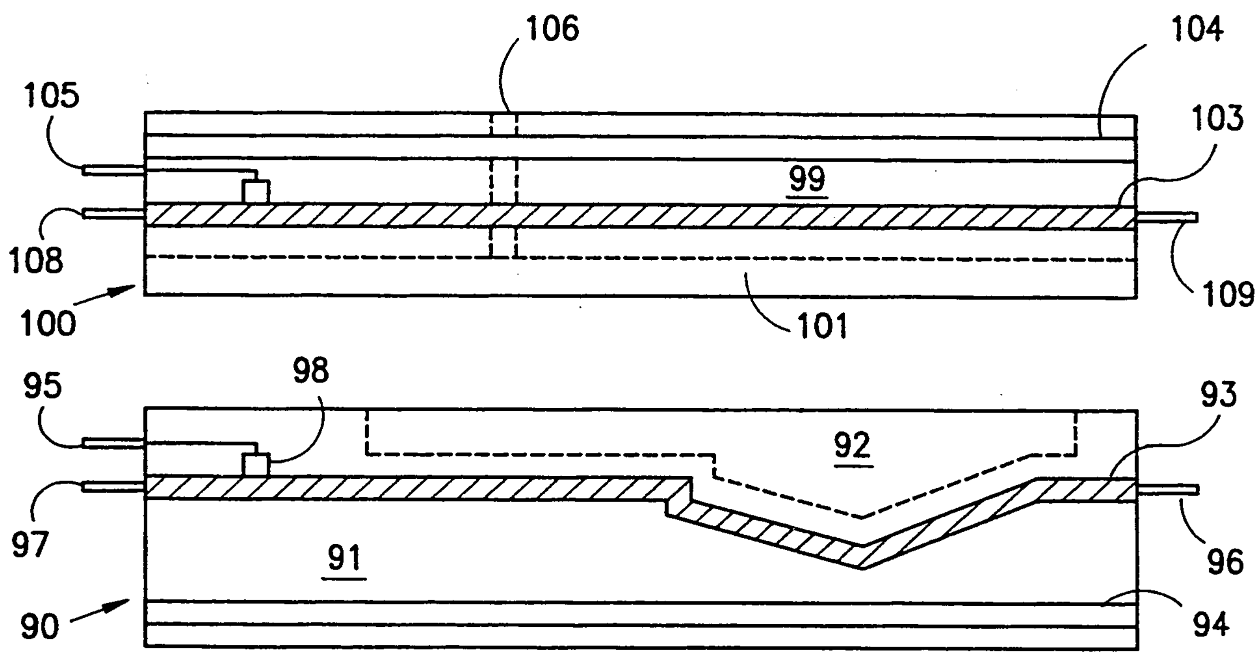

FIG. 14

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Filed on 10 March 1999 (10.03.1999)

(71) Applicant (for all designated States except US): SOUTHERN RESEARCH INSTITUTE [US/US]; 2000 Ninth Avenue South, Birmingham, AL 35205 (US).

(72) Inventors; and
(75) Inventors/Applicants (for US only): JACKSON, Thomas, E. [US/US]; 3420 Sagewood Trail, Birmingham, AL 35243 (US). HUSMAN, George, E. [US/US]; 320 Bradberry Lane, Birmingham, AL 35242 (US).

(74) Agents: PETTIT, George, R. et al.; Pollock, Vande Sande & Amernick, 1990 M Street, N.W., #800, Washington, DC 20036 (US).

(81) Designated States *(national)*: AU, CA, CN, IL, JP, MX, NO, SG, US.

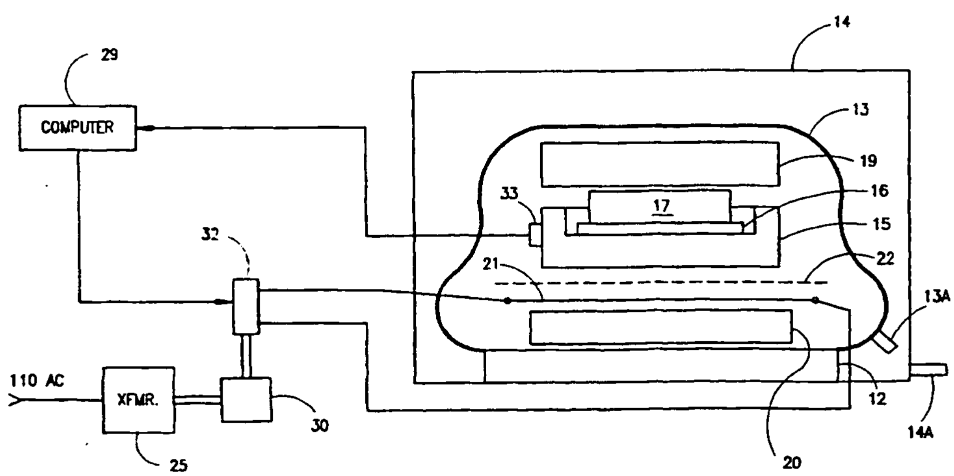
(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published:
— *With international search report.*

(88) Date of publication of the international search report: 18 January 2001

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: HEATED TOOLING APPARATUS AND METHOD FOR PROCESSING COMPOSITE AND PLASTIC MATERIAL



(57) Abstract: A method and apparatus for heating composite or plastic materials (16) which are formed into a final product. Heat is generated from a carbon fabric (21) which may be embedded in a ceramic tool base using conventional ceramic molding techniques. The generated heat is uniformly distributed over the surface area of the carbon fabric (21), and the heat transfer from the ceramic tool base to the composite or plastic material (16) may be controlled to maximize heat flow into the composite or plastic material. The heat source and material being formed may be placed in a vacuum environment to aid in the formation of the material about a mold surface. The temperature of the material being formed may be maintained at a constant temperature by controlling the current supplied to the carbon fabric in proportion to a measured temperature. The heat source may include cooling channels which permit the ceramic tool to be cooled.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/05717

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :B29C 33/02, 33/38, 70/44, 70/48
US CL :249/78, 79, 111; 264/225, 226, 404, 571, 604, 654; 425/389, 390
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 249/78, 79, 111; 264/225, 226, 404, 571, 604, 654, Dig.46; 425/389, 390, Dig.13

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,656,231 A (BLACKMORE) 12 August 1997, see figures 7-11; col. 4, lines 29-46; col. 8, lines 44-67.	12, 13, 22-25 ----- 22
Y	US 5,236,646 A (COCHRAN et al) 17 August 1993, see figure 3 and col. 5, lines 45-64.	22
A	US 5,863,452 A (HARSHBERGER, JR. et al) 26 January 1999, see figures 1-2.	1

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search	Date of mailing of the international search report
22 AUGUST 2000	07 SEP 2000

Name and mailing address of the ISA/US	Authorized officer
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Facsimile No. (703) 305-3230	Telephone No. (703) 308-0651